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(54) **BIDIRECTIONAL FORWARDING DETECTION OVER NETWORK VIRTUALIZATION USING GENERIC ROUTING ENCAPSULATION**

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(51) **Int. Cl.**

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H04L 12/46	(2006.01)
H04L 12/26	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 41/06*** (2013.01); ***H04L 12/4633*** (2013.01); ***H04L 12/4641*** (2013.01); *H04L 43/0811* (2013.01)

(58) **Field of Classification Search**

CPC . H04L 12/4633; H04L 12/4641; H04L 12/24; H04L 12/46; H04L 41/06; H04L 43/0811; H04L 45/28; H04L 45/22; H04L 45/50; H04L 45/02; H04L 45/586; H04L 47/825; H04L 49/70

See application file for complete search history.

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(57) **ABSTRACT**

A system and method for detecting a communication status includes generating, at an originating virtual tunnel end point (VTEP), a network virtualization using generic routing encapsulation (NVGRE) data packet in accordance with NVGRE protocols. A bidirectional forwarding detection (BFD) data packet is encapsulated in the NVGRE data packet to provide an NVGRE BFD data packet. The NVGRE BFD data packet is transmitted to a terminating VTEP to establish a BFD session over an NVGRE tunnel. A communication status of the NVGRE tunnel is determined for the BFD session based on a reply BFD data packet received from the terminating VTEP in accordance with a receiving time interval.

17 Claims, 6 Drawing Sheets

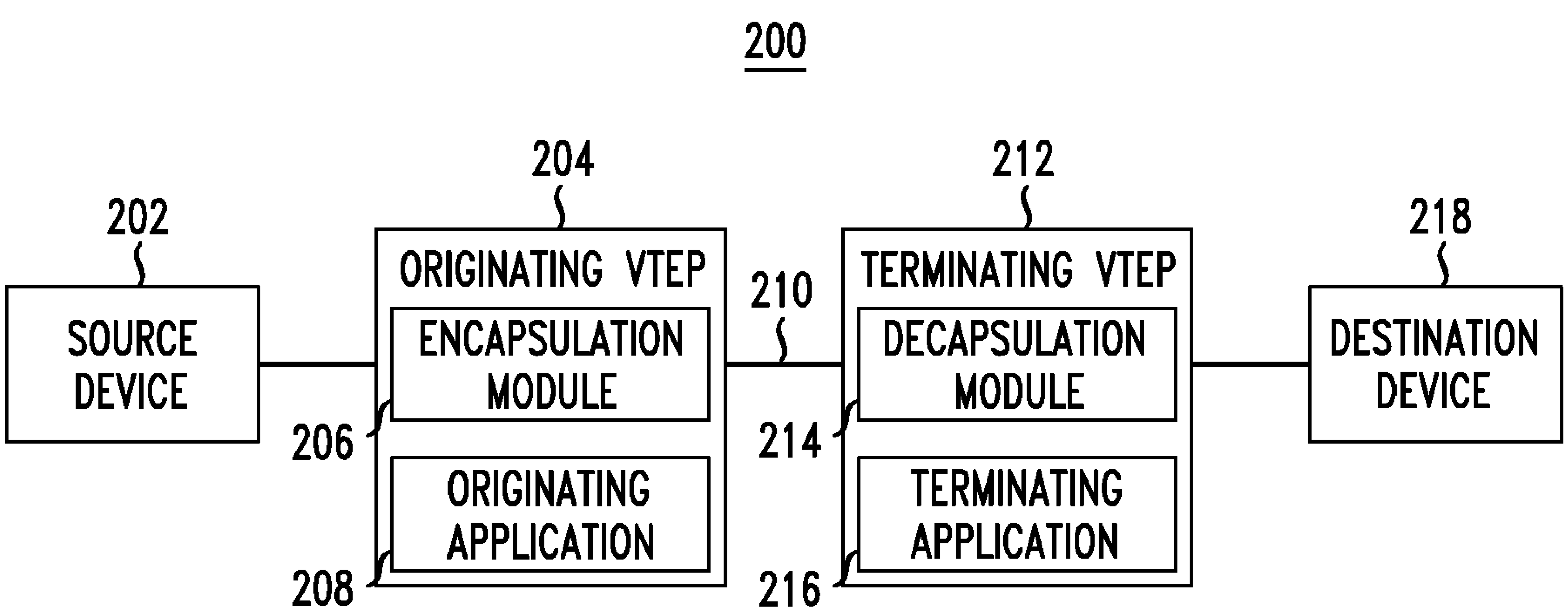

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FIG. 1

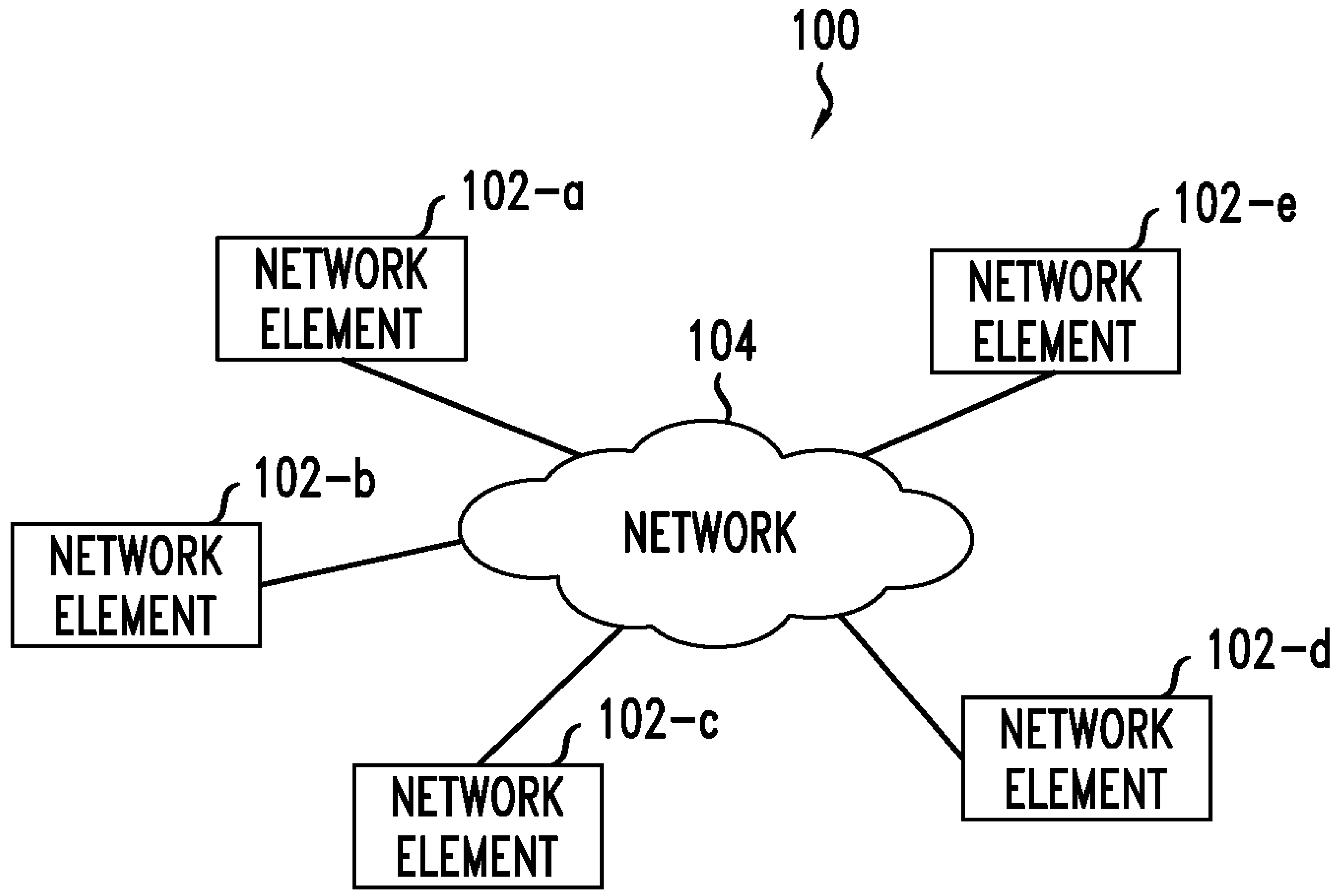

100
102-a
NETWORK ELEMENT
102-e
NETWORK ELEMENT
104
NETWORK
102-b
NETWORK ELEMENT
102-d
NETWORK ELEMENT
102-c
NETWORK ELEMENT

FIG. 2

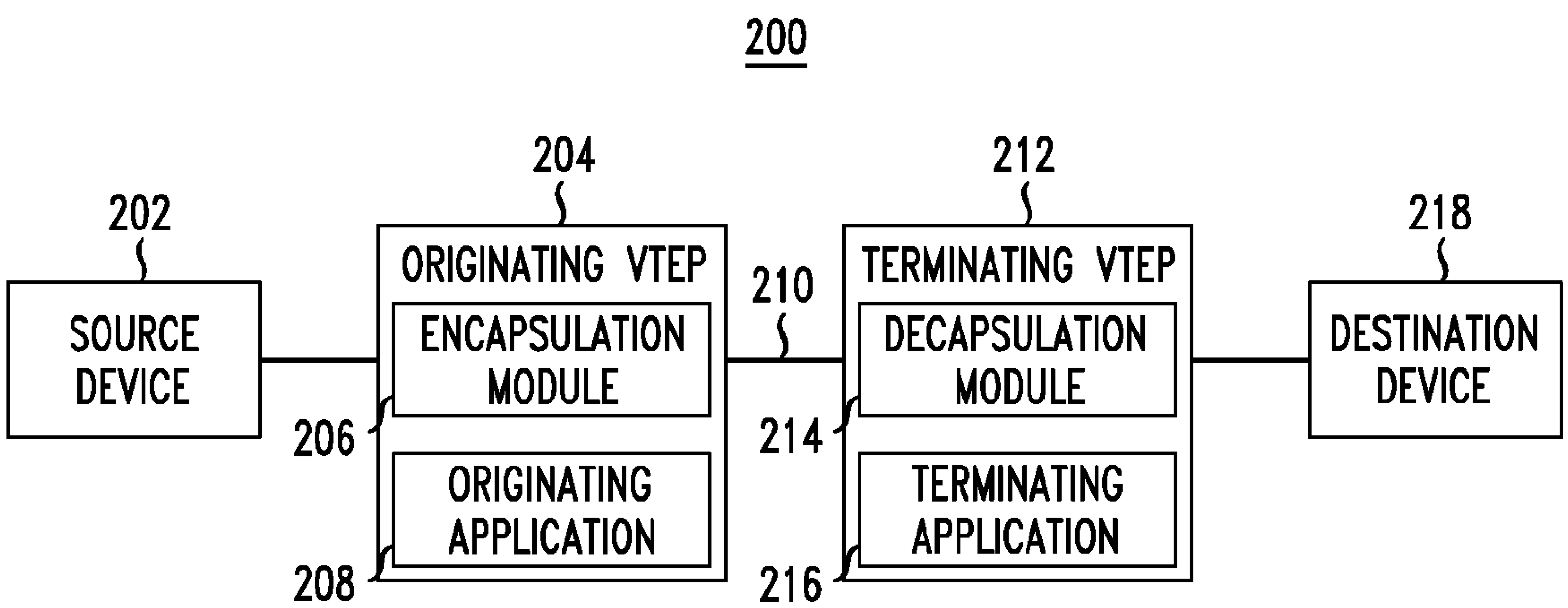

200
202
SOURCE DEVICE
204
ORIGINATING VTEP
ENCAPSULATION MODULE
206
ORIGINATING APPLICATION
208
210
212
TERMINATING VTEP
DECAPSULATION MODULE
214
TERMINATING APPLICATION
216
218
DESTINATION DEVICE

FIG. 3

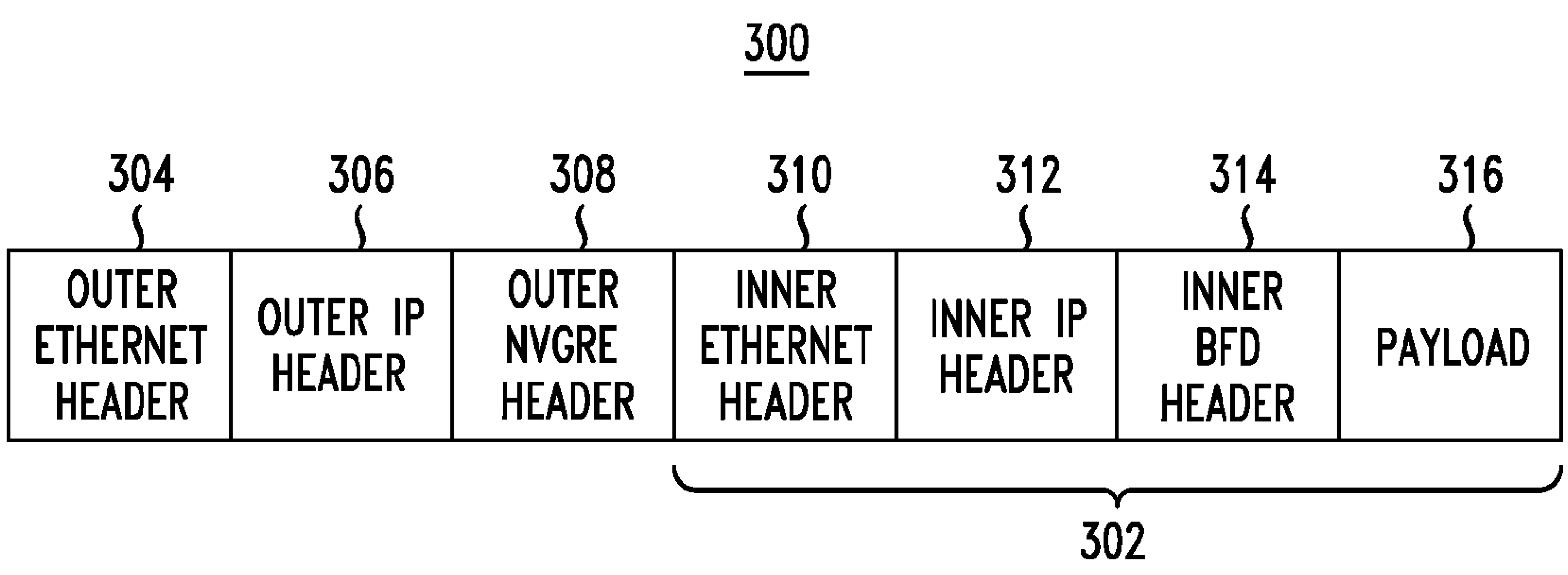

300
304
OUTER ETHERNET HEADER
306
OUTER IP HEADER
308
OUTER NVGRE HEADER
310
INNER ETHERNET HEADER
312
INNER IP HEADER
314
INNER BFD HEADER
316
PAYLOAD
302

FIG. 4

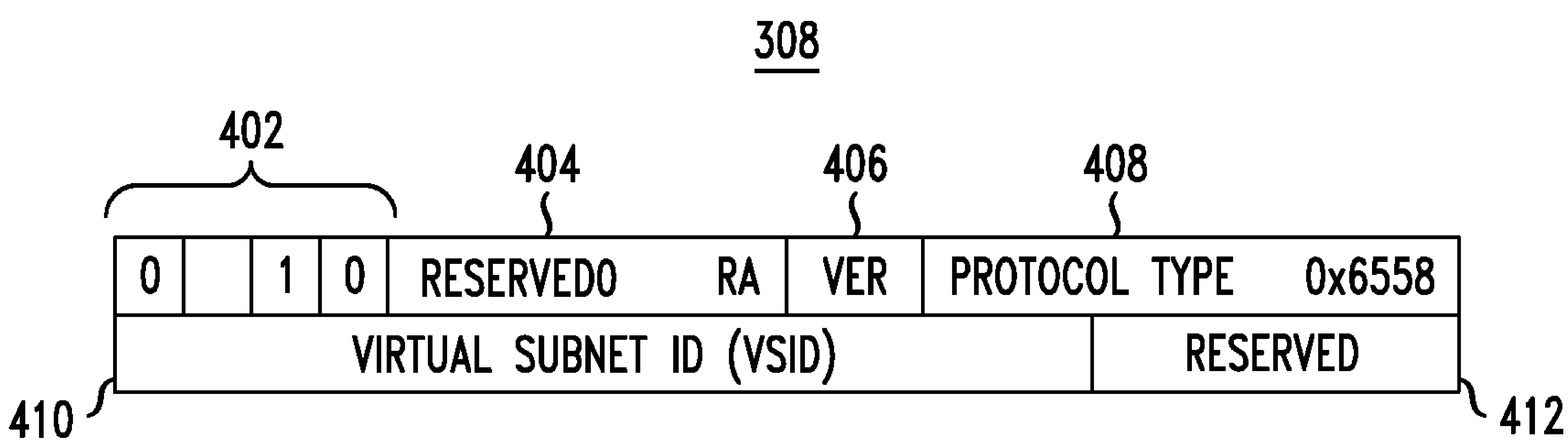

308
402
404
406
408
0
1
0
RESERVED0
RA
VER
PROTOCOL TYPE
0x6558
VIRTUAL SUBNET ID (VSID)
RESERVED
410
412

FIG. 5

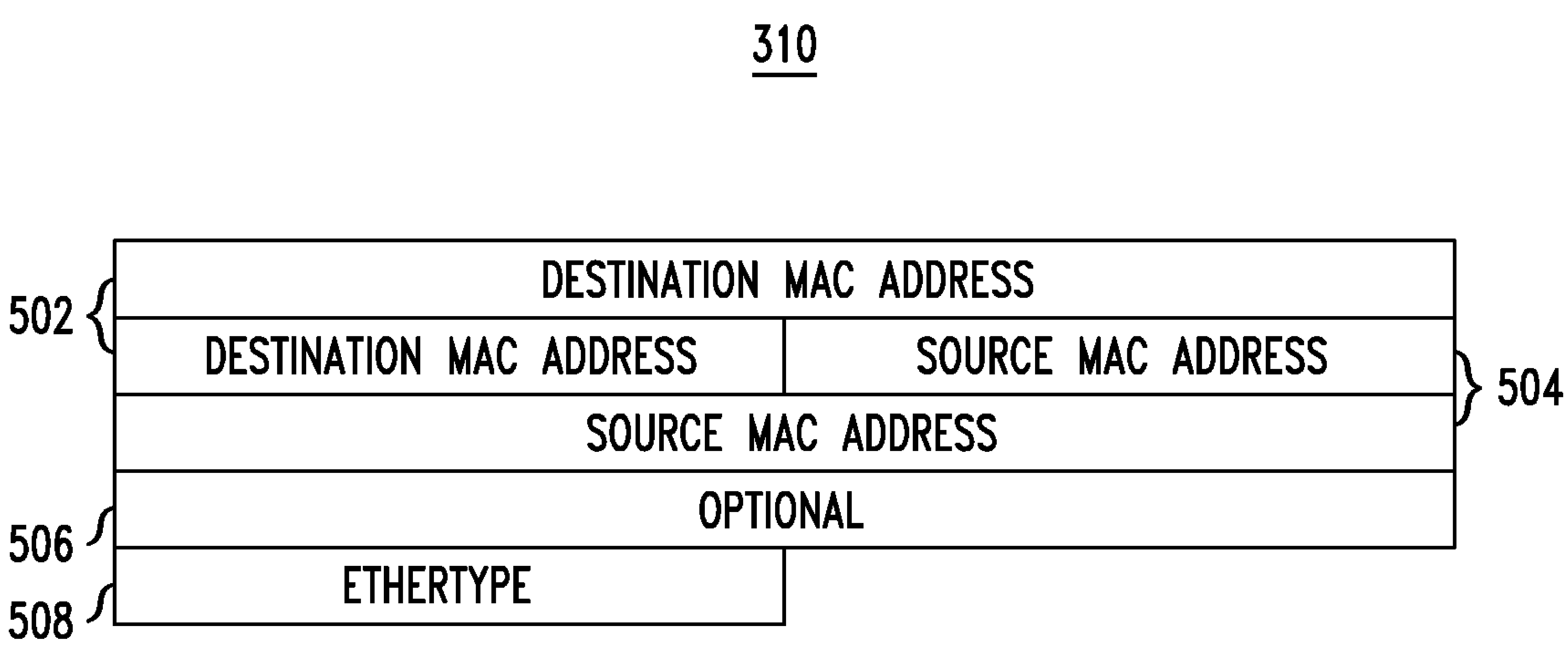

310
DESTINATION MAC ADDRESS
502
DESTINATION MAC ADDRESS
SOURCE MAC ADDRESS
504
SOURCE MAC ADDRESS
OPTIONAL
506
ETHERTYPE
508

FIG. 6

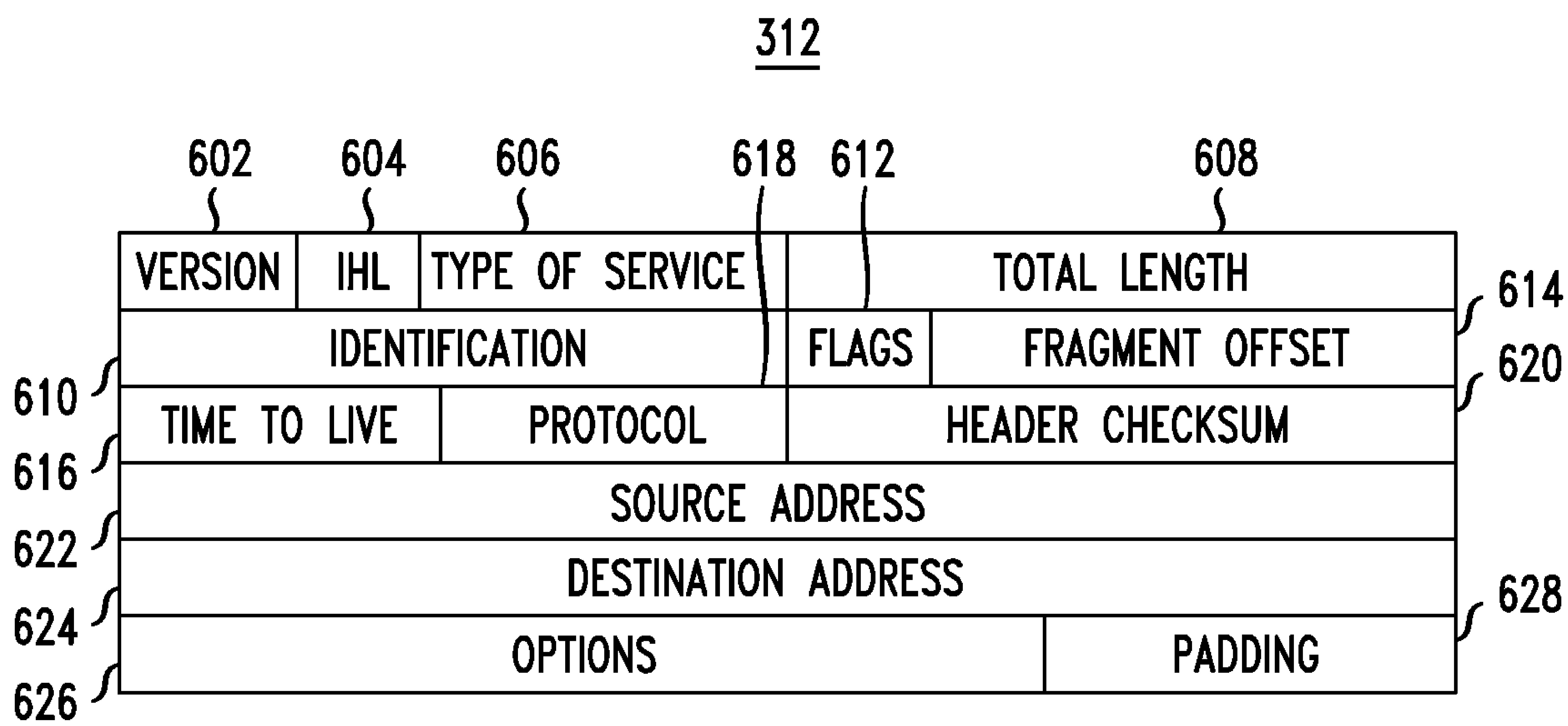

312
602
604
606
618
612
608
VERSION
IHL
TYPE OF SERVICE
TOTAL LENGTH
614
IDENTIFICATION
FLAGS
FRAGMENT OFFSET
620
610
TIME TO LIVE
PROTOCOL
HEADER CHECKSUM
616
SOURCE ADDRESS
622
DESTINATION ADDRESS
628
624
OPTIONS
PADDING
626

FIG. 7

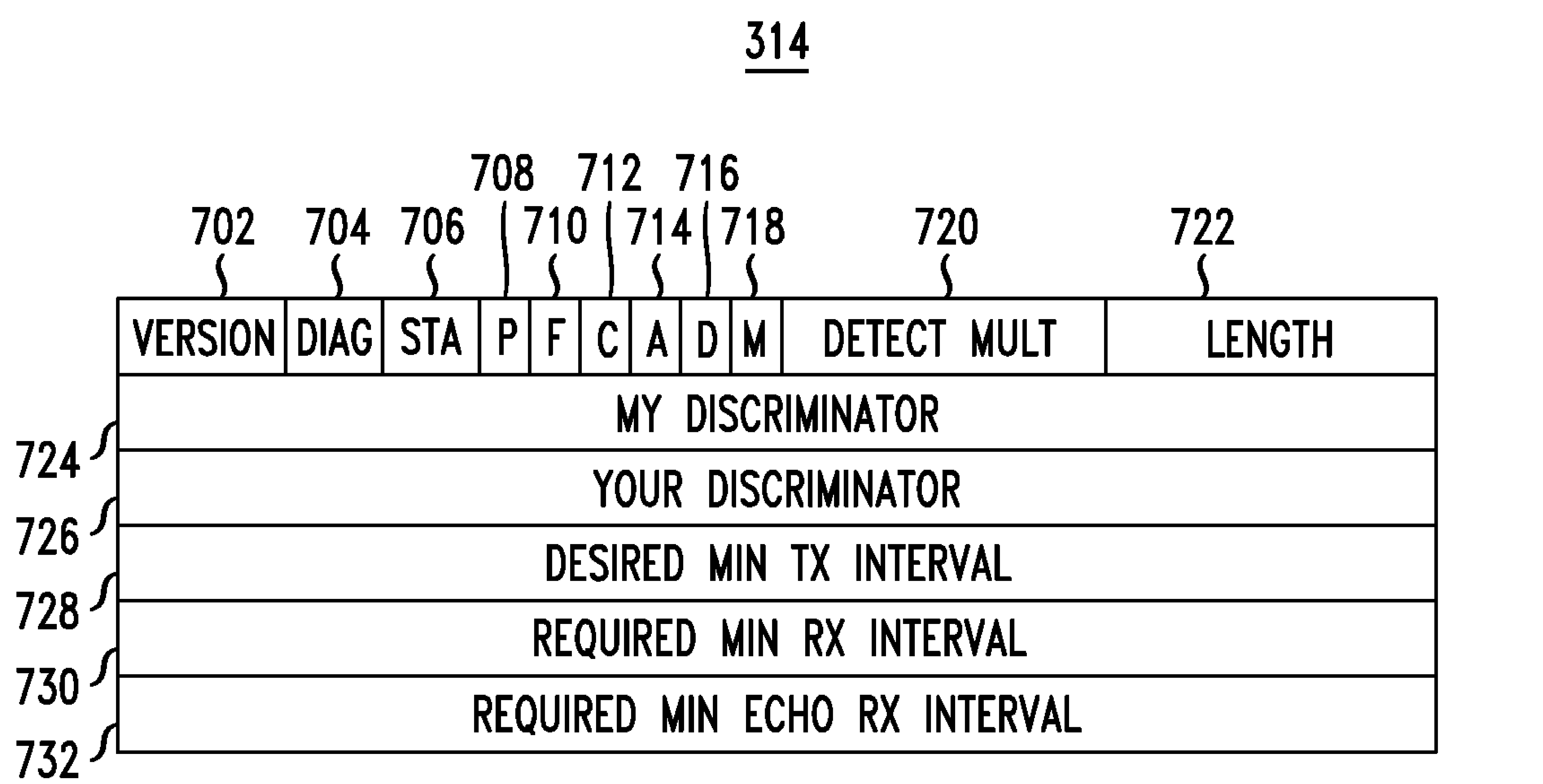

314
708
712
716
702
704
706
710
714
718
720
722
VERSION
DIAG
STA
P
F
C
A
D
M
DETECT MULT
LENGTH
MY DISCRIMINATOR
724
YOUR DISCRIMINATOR
726
DESIRED MIN TX INTERVAL
728
REQUIRED MIN RX INTERVAL
730
REQUIRED MIN ECHO RX INTERVAL
732

FIG. 8

800

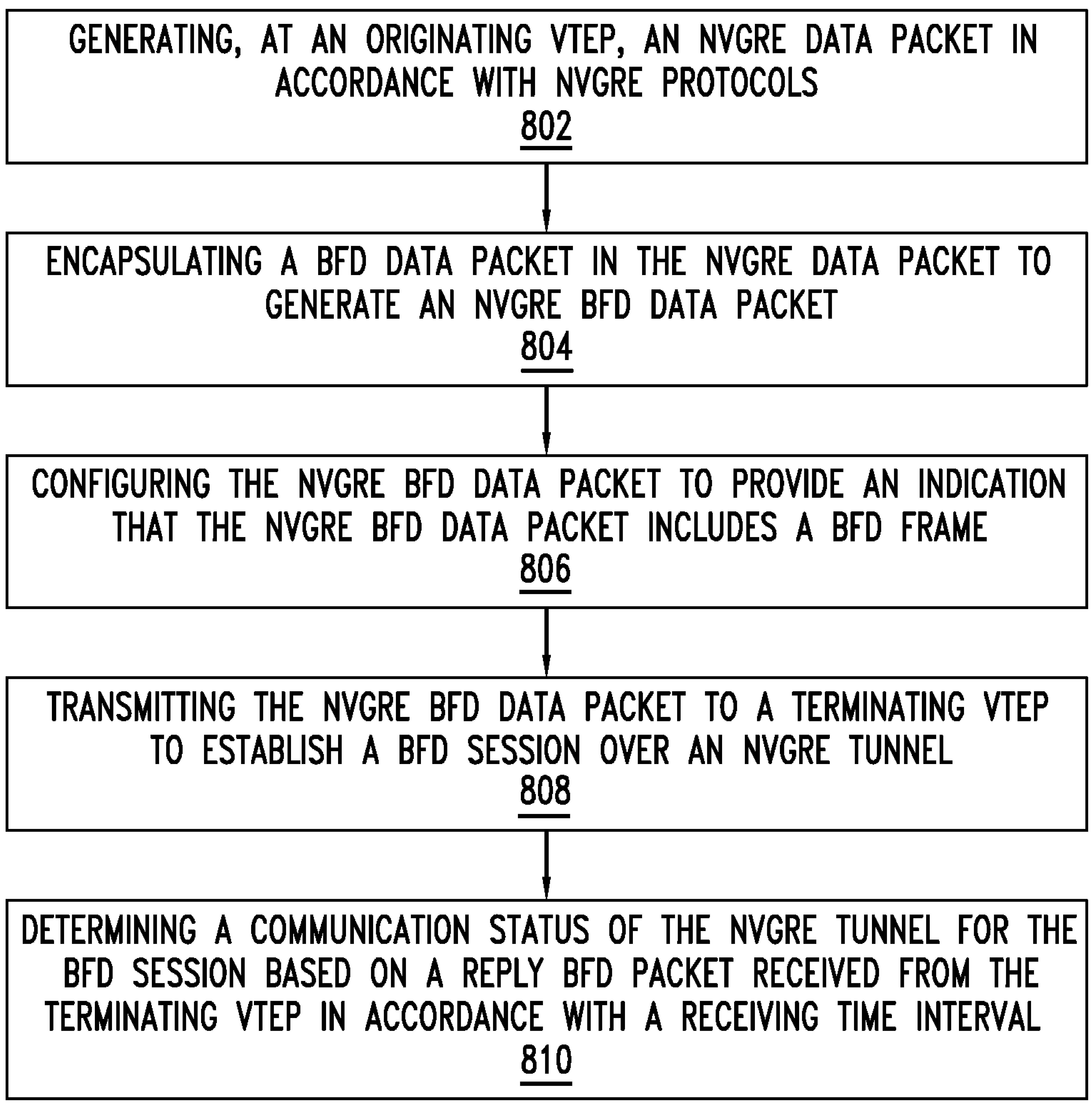

GENERATING, AT AN ORIGINATING VTEP, AN NVGRE DATA PACKET IN ACCORDANCE WITH NVGRE PROTOCOLS
802
ENCAPSULATING A BFD DATA PACKET IN THE NVGRE DATA PACKET TO GENERATE AN NVGRE BFD DATA PACKET
804
CONFIGURING THE NVGRE BFD DATA PACKET TO PROVIDE AN INDICATION THAT THE NVGRE BFD DATA PACKET INCLUDES A BFD FRAME
806
TRANSMITTING THE NVGRE BFD DATA PACKET TO A TERMINATING VTEP TO ESTABLISH A BFD SESSION OVER AN NVGRE TUNNEL
808
DETERMINING A COMMUNICATION STATUS OF THE NVGRE TUNNEL FOR THE BFD SESSION BASED ON A REPLY BFD PACKET RECEIVED FROM THE TERMINATING VTEP IN ACCORDANCE WITH A RECEIVING TIME INTERVAL
810

FIG. 9

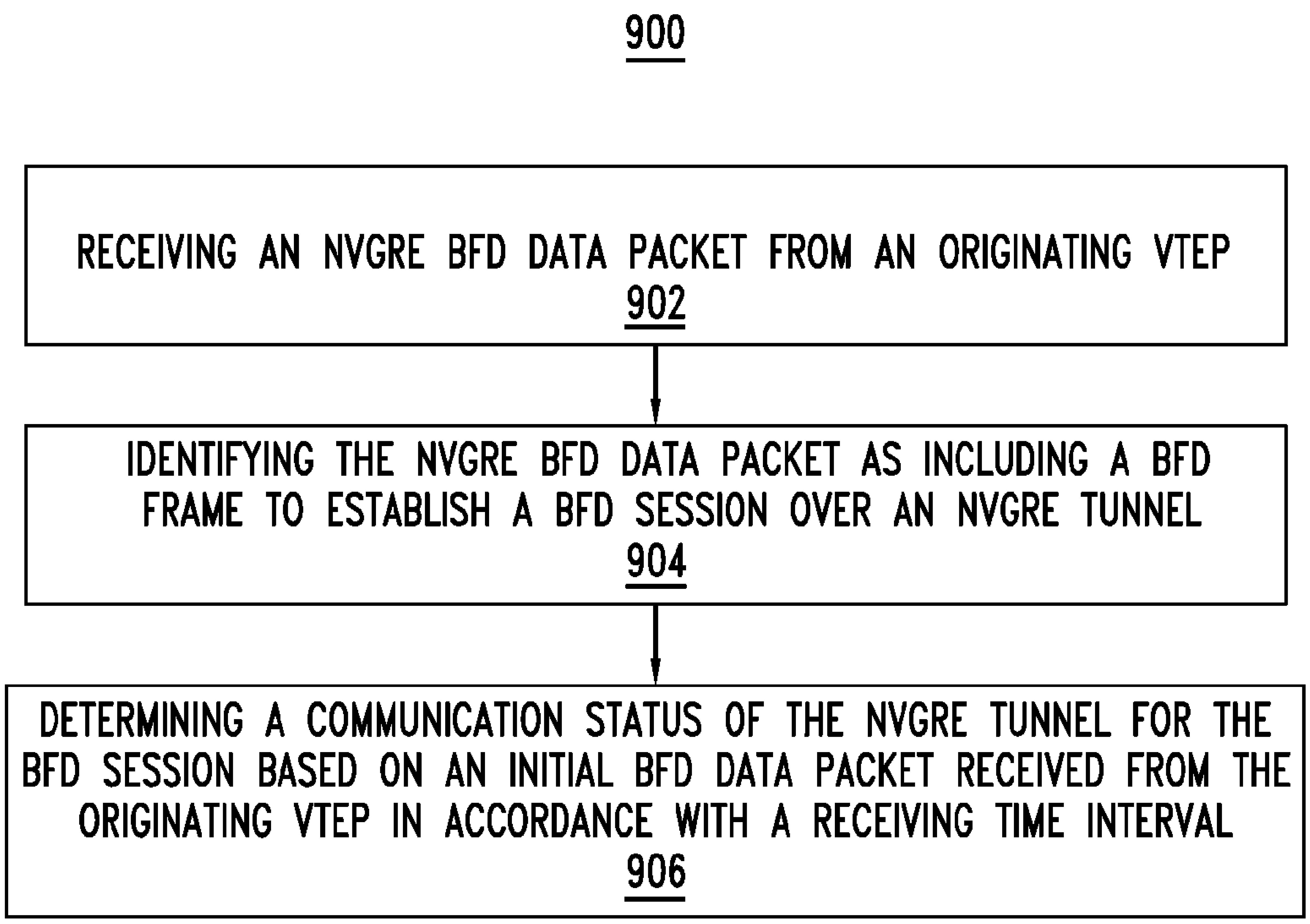
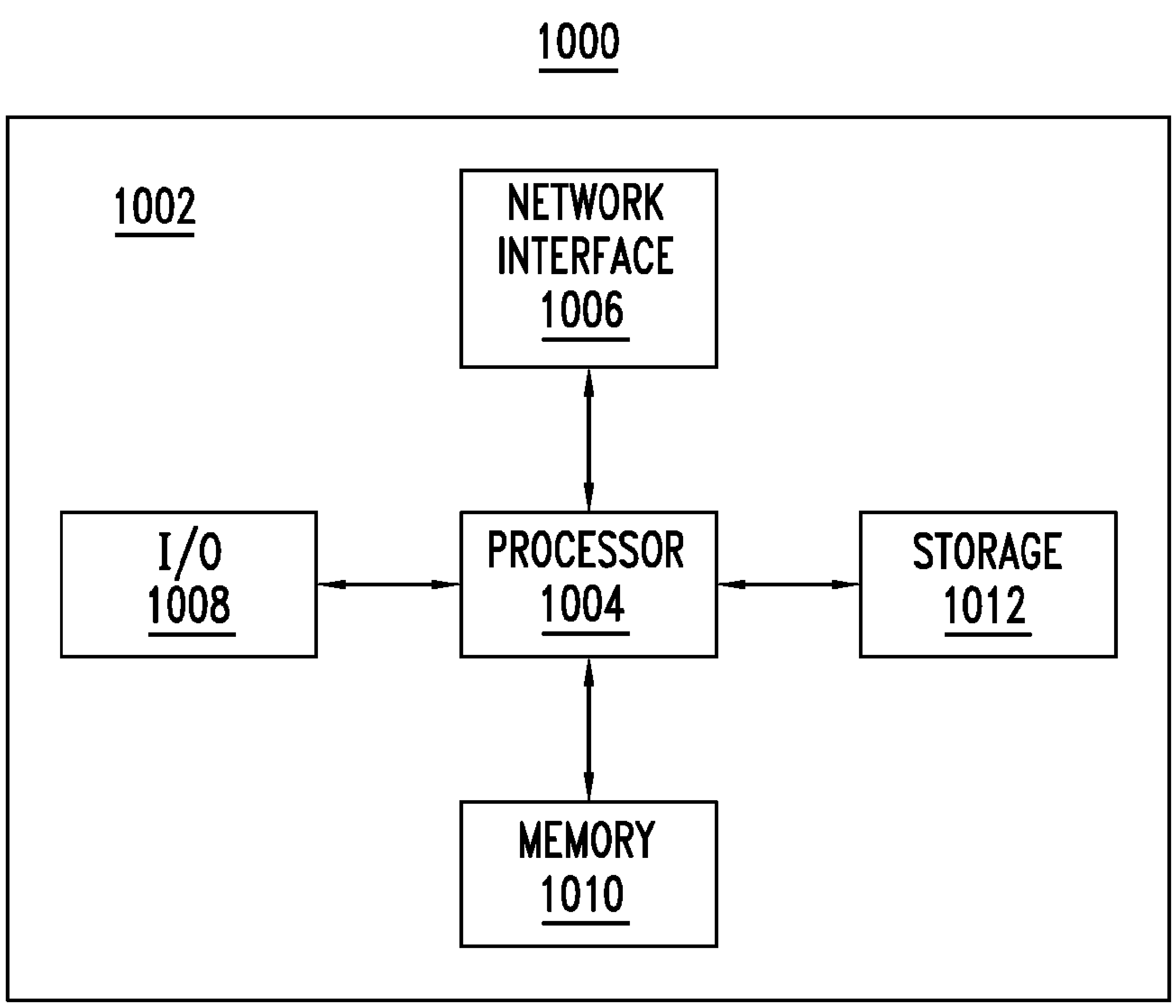

900
RECEIVING AN NVGRE BFD DATA PACKET FROM AN ORIGINATING VTEP
902
IDENTIFYING THE NVGRE BFD DATA PACKET AS INCLUDING A BFD FRAME TO ESTABLISH A BFD SESSION OVER AN NVGRE TUNNEL
904
DETERMINING A COMMUNICATION STATUS OF THE NVGRE TUNNEL FOR THE BFD SESSION BASED ON AN INITIAL BFD DATA PACKET RECEIVED FROM THE ORIGINATING VTEP IN ACCORDANCE WITH A RECEIVING TIME INTERVAL
906

FIG. 10


1000
1002
NETWORK INTERFACE
1006
I/O
1008
PROCESSOR
1004
STORAGE
1012
MEMORY
1010

BIDIRECTIONAL FORWARDING DETECTION OVER NETWORK VIRTUALIZATION USING GENERIC ROUTING ENCAPSULATION

BACKGROUND OF THE INVENTION

The present invention relates generally to the detection of communication failures and more particularly to bidirectional forwarding detection for detecting network communication failures over network virtualization using generic routing encapsulation tunnels.

Network virtualization using generic routing encapsulation (NVGRE) is a network virtualization technology adapted to ameliorate scalability problems associated with large cloud computing deployments. NVGRE uses an encapsulation technique similar to that used by virtual local area networks (VLANs) to encapsulate media access control (MAC) based layer 2 Ethernet frames within layer 3 packets. In accordance with an NVGRE tunneling mechanism, a first device, referred to as an originating virtual tunnel end point, encapsulates a data packet in accordance with NVGRE protocols, and transmits the encapsulated data packet to a second device, referred to as the terminating virtual tunnel end point. The terminating virtual tunnel end point decapsulates the data packet and forwards the decapsulated data packet to an intended destination device.

An increasingly important feature of network management is the rapid detection of communication failures between adjacent systems in order to more quickly establish alternative paths. Bidirectional forwarding detection (BFD) is a common method used in networking equipment for rapid fault detection. However, there is currently no mechanism for supporting BFD to detect failures between end points in NVGRE tunneling.

BRIEF SUMMARY OF THE INVENTION

In one embodiment, systems and methods for detecting a communication status at an originating virtual tunnel end point (VTEP) include generating, at the originating VTEP, a network virtualization using generic routing encapsulation (NVGRE) data packet in accordance with NVGRE protocols. A bidirectional forwarding detection (BFD) data packet is encapsulated in the NVGRE data packet to generate an NVGRE BFD data packet. The NVGRE BFD data packet is transmitted to a terminating VTEP to establish a BFD session over an NVGRE tunnel. A communication status of the NVGRE tunnel is determined for the BFD session based on a reply BFD data packet received from the terminating VTEP in accordance with a receiving time interval.

In one embodiment, the NVGRE BFD data packet may be configured to provide an indication that the NVGRE BFD data packet includes a BFD frame. The indication may be provided by setting a router alert option in an outer NVGRE header of the NVGRE data packet. The indication may also be provided by setting a destination media access control (MAC) address in an inner Ethernet header of the NVGRE BFD data packet to a predetermined value.

The communication status of the NVGRE tunnel may be determined based on not receiving the reply BFD data packet from the terminating VTEP within the receiving time interval. The communication status of the NVGRE tunnel may be determined to be down when a particular number of reply BFD data packets are not received within their respective receiving time interval. The originating VTEP may send initial BFD data packets to the terminating VTEP based on a transmission time interval.

Establishing the BFD session over the NVGRE tunnel may further include receiving a responding BFD data packet from the terminating VTEP. The responding BFD data packet may have a your discriminator field in a BFD header set to a value equal to a my discriminator field in a BFD header of the NVGRE BFD data packet. The receiving time intervals may be negotiated based on a value set in a required minimum receiving interval field of the NVGRE BFD data packet and a value set in a required minimum receiving interval field of the responding BFD data packet.

In another embodiment, a system and method for detecting communication failures at a terminating VTEP include receiving a NVGRE BFD data packet from an originating VTEP to establish a BFD session over an NVGRE tunnel. The NVGRE BFD data packet comprises an NVGRE data packet in accordance with NVGRE protocols encapsulating a BFD data packet. A communication status of the NVGRE tunnel is determined based on an initial BFD data packet received from the originating VTEP in accordance with a receiving time interval.

These and other advantages of the invention will be apparent to those of ordinary skill in the art by reference to the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a high-level overview of a communications system;

FIG. **2** shows a system for communicating between an originating and terminating virtual tunnel end point;

FIG. **3** shows an exemplary NVGRE BFD data packet;

FIG. **4** shows an exemplary outer NVGRE header of the NVGRE BFD data packet;

FIG. **5** shows an exemplary inner Ethernet header of the NVGRE BFD data packet;

FIG. **6** shows an exemplary inner IP header of the NVGRE BFD data packet;

FIG. **7** shows an exemplary inner BFD header of the NVGRE BFD data packet;

FIG. **8** shows a flow diagram of a method for detecting communication failures at an originating VTEP;

FIG. **9** shows a flow diagram of a method for detecting communication failures at a terminating VTEP; and

FIG. **10** shows components of an exemplary computer that may be used for detecting communication failures.

DETAILED DESCRIPTION

FIG. **1** shows a high-level overview of a communications system **100**, in accordance with one or more embodiments. Communications system **100** includes network element **102**-*a*, **102**-*b*, **102**-*c*, **102**-*d*, **102**-*e*, etc. (collectively referred to as network element **102**) communicatively coupled to network **104**. Network element **102** may include any type of device capable of communicating over network **104**. For example, network element **102** may be a server computer, such as, e.g., an email server, a database server, a virtual machine, a software application, etc. In another example, network element **102** may be a router. It should be understood that communications system **100** may include any number of network elements **102** and that network element **102** may refer to any one of the network elements.

Network elements **102** communicate over network **104**. Network **104** may include any type of network or combinations of different types of networks. For example, network **104** may include the Internet, an intranet, a local area network (LAN), a wide area network (WAN), a wired and/or wireless network, a Fibre Channel storage area network (SAN), a cellular communications network, etc. Other types of networks are also contemplated.

In one embodiment, two or more network elements **102** within network **104** communicate using network virtualization using generic routing encapsulation (NVGRE). NVGRE employs an encapsulation technique to encapsulate media access control (MAC) based layer-**2** Ethernet frames within layer **3** packets. In accordance with an NVGRE tunneling mechanism, an originating virtual tunnel end point (VTEP), such as, e.g., network element **102**-*a*, encapsulates a data packet in accordance with NVGRE protocols, and transmits the encapsulated data packet to a terminating VTEP, such as, e.g., network elements **102**-*b*. The terminating VTEP decapsulates the data packet and forwards the decapsulated data packet to an intended destination device.

FIG. **2** shows a system **200** for implementing NVGRE, in accordance with one or more embodiments. System **200** includes source device **202**, originating VTEP **204**, terminating VTEP **212**, and destination device **218**, each of which may be represented by network elements **102** in communications system **100**.

Originating VTEP **204** comprises encapsulation module **206** and originating application **208**. Encapsulation module **206** is configured to encapsulate a data packet in accordance with NVGRE protocols and transmit the NVGRE packet via link **210** to terminating VTEP **212** for destination device **218**. Link **210** may include a network connection, a direct connection, etc. In one embodiment, the data packet includes a bidirectional forwarding detection (BFD) data packet. However the data packet may also include any other type of data packet, such as, e.g., an Internet Protocol (IP) data packet. In one example, the data packet is generated by source device **202**. In another example, the data packet is generated by originating application **208**.

Originating application **208** may include any type of application having any type of functionality. In one embodiment, originating application **208** may be a BFD task for network fault detection, which creates the BFD data packet and provides it to encapsulation module **206**. Other types of originating application **208** are also contemplated, such as, e.g., an operations, administration, and maintenance (OAM) application.

The data packet may be encapsulated by encapsulation module **206** in accordance with NVGRE protocols to provide an NVGRE data packet. The NVGRE data packet is transmitted via link **210** to terminating VTEP **202**. Terminating VTEP **212** comprises decapsulation module **214** and terminating application **216**. Decapsulation module **214** is configured to decapsulate the data packet from the NVGRE data packet. In one embodiment, decapsulation module **214** transmits the decapsulated data packet to destination device **218**. In another embodiment, decapsulation module **214** transmits the decapsulated data packet to terminating application **216**. Terminating application **216** includes any type of application having any type of functionality. For example, terminating application **216** may include a BFD task, an OAM application, etc.

In accordance with one or more embodiments, system **200** may be configured for implementing BFD over NVGRE. Advantageously, BFD over NVGRE may provide for rapid detection of communication failures in order to more quickly establish alternative paths. To implement BFD over NVGRE, a BFD data packet is encapsulated in accordance with NVGRE protocols. The BFD data packet may be generated by source device **202** or originating application **208** (e.g., a BFD task). The BFD data packet is encapsulated in accordance with NVGRE protocols by encapsulation module **206** of originating VTEP **204** to generate an NVGRE BFD data packet.

FIG. **3** shows an exemplary NVGRE BFD data packet **300**, in accordance with one or more embodiments. NVGRE BFD data packet **300** includes BFD data packet **302** encapsulated in accordance with NVGRE protocols. NVGRE BFD data packet **300** includes outer header portions in accordance with NVGRE protocols and inner header portions of encapsulated BFD data packet **302**. Outer header portions of NVGRE BFD data packet **300** include outer Ethernet header **304**, outer IP (internet protocol) header **306**, and outer NVGRE header **308**. Inner header portions of NVGRE BFD data packet **300** include inner Ethernet header **310**, inner IP header **312**, inner BFD header **314**, and optionally payload **316**. BFD over NVGRE is implemented on system **200** by configuring or setting parameters of NVGRE BFD data packet **300**.

FIG. **4** shows an exemplary outer NVGRE header **308** of NVGRE BFD data packet **300**, in accordance with one or more embodiments. Outer NVGRE header **308** comprises a plurality of sections. For example, outer NVGRE header **308** may include information section **402**, first reserved section **404** (referred to as the "Reserved**0** section"), version section **406**, protocol type section **408**, virtual subnet identifier (VSID) section **410**, and second reserved section **412**. Outer NVGRE header **308** may also include other sections.

Originating VTEP **204** configures parameters of outer NVGRE header **308** for BFD over NVGRE. VSID **410** is set to be the same as that of the NVGRE segment that is being verified. This ensures that NVGRE BFD data packet **300** travels over the same data path as any other end system data traveling over this NVGRE segment.

The NVGRE router alert option, shown as RA in outer NVGRE header **308** of FIG. **4**, is also set in Reserved**0** section **404** of outer NVGRE header **308**. For example, the router alert option RA may include a router alert bit, which is set by updating its value. In one example, a router alert option RA indicative of a BFD frame in NVGRE BFD data packet **300** would alert terminating VTEP **212** not to forward the NVGRE frame to destination device **218** and instead to perform local processing (e.g., BFD).

Originating VTEP **204** also configures parameters of inner Ethernet header **310** for implementing BFD over NVGRE. FIG. **5** shows an exemplary inner Ethernet header **310** of NVGRE BFD data packet **300**, in accordance with one or more embodiments. Inner Ethernet header **310** comprises a plurality of sections. For example, inner Ethernet header **310** may include destination MAC (media access control) address **502**, source MAC address **504**, optional section **506**, and EtherType **508**. Inner Ethernet header **310** may also include other sections.

Parameters of inner Ethernet header **310** are configured by setting destination MAC address **502** to a well-defined, predetermined value to indicate the payload of NVGRE BFD data packet **300** to be a BFD data packet. For example, destination MAC address **502** may be set to 00-00-5E-90-XX-XX, where X is any hexadecimal digit, e.g., a value assigned by the Internet Assigned Numbers Authority (IANA). Source MAC address **504** is also set to the MAC address of originating VTEP **204**. In one embodiment, source MAC address **504** is not learned in the MAC address table as this represents NVGRE BFD. Typically, NVGRE carries layer **2**/Ethernet data and a VTEP receiving the data learns the source MAC address from a MAC address table. However, since NVGRE BFD data packet **300** encapsulates a BFD control packet under an NVGRE packet, there is no need to learn source MAC address **504** from the MAC address table.

In addition, parameters of inner IP header **312** are configured for implementing BFD over NVGRE by originating VTEP **204**. FIG. **6** shows an exemplary inner IP header **312** of NVGRE BFD data packet **300**, in accordance with one or more embodiments. Inner IP header **312** in FIG. **6** is illustratively shown as an IPv4 (Internet Protocol version 4) header, however other formats are also contemplated, such as, e.g., IPv6 (Internet Protocol version 6). Inner IP header **312** comprises a plurality of sections. For example, inner IP header **312** may include version **602**, IHL (internet header length) **604**, type of service **606**, total length **608**, identification **610**, flags **612**, fragment offset **614**, time to live **616**, protocol **618**, header checksum **620**, source address **622**, destination address **624**, options **626**, and padding **628**. Inner IP header **312** may also include other sections.

Parameters of inner IP header **312** are configured for BFD over NVGRE by setting source address **622** to the routable address of the sender, e.g., originating VTEP **204**. Destination address **624** is a, e.g., randomly chosen IPv4 address from the range 127/8 or IPv6 address from the range 0:0:0:0:0:FFFF:127/104. Time to live **616** is also set to **255**.

Parameters of inner BFD header **314** are additionally configured for BFD over NVGRE by originating VTEP **204**. FIG. **7** shows an exemplary inner BFD header **314** of NVGRE BFD data packet **300**, in accordance with one or more embodiments. Inner BFD header **314** comprises a plurality of sections. For example, inner BFD header **314** may include version **702**, diagnostic (diag) **704**, state (sta) **706**, poll (P) **708**, final (F) **710**, control plane independent (C) **712**, authentication present (A) **714**, demand (D) **716**, multipoint (M) **718**, detect time multiplier (Dect Mult) **720**, length **722**, my discriminator **724**, your discriminator **726**, desired minimum transmission interval **728**, required minimum receiving interval **730**, and required minimum echo receiving interval **732**. Inner BFD header **314** may also include other sections, such as, e.g., authentication sections.

Parameters of inner BFD header **314** are configured by setting my discriminator **724** to some, e.g., random valid value (e.g., 10 or 20) and your discriminator **726** to 0. My discriminator **724** is a unique, nonzero discriminator generated by originating VTEP **204** and used to demultiplex multiple BFD sessions between a same pair of systems. Your discriminator **726** is the discriminator received from the corresponding remote system and reflects back the received value of my discriminator (or zero if the value is unknown). Timer values for desired minimum transmission interval **728** and required minimum receiving interval **730** are also set. Desired minimum transmission interval **728** is the minimum interval that originating VTEP **204** transmits NVGRE BFD data packets. Required minimum receiving interval **730** is the minimum interval between receiving BFD data packets.

NVGRE BFD data packet **300**, as configured above, is used to establish a BFD session between originating VTEP **204** and terminating VTEP **212** over an NVGRE tunnel. Originating VTEP **204** transmits NVGRE BFD data packet **300** via link **210** to terminating VTEP **212**. Decapsulation module **214** of terminating VTEP **212** identifies NVGRE BFD data packet **300** as including an NVGRE BFD frame and decapsulates the BFD data packet **302** from NVGRE BFD data packet **300**. Decapsulation module **214** identifies NVGRE BFD data packet **300** as including an NVGRE BFD frame based on the router alert in outer NVGRE header **308** and the predetermined value of destination MAC address **502** of inner Ethernet header **310**. Terminating VTEP **212** configures parameters of decapsulated BFD data packet **302** by setting your discriminator **726** to the received value of my discriminator **724** from NVGRE BFD data packet **300** (as received from originating VTEP **204**). Terminating VTEP **212** also sets timer values for desired minimum transmission interval **728** and required minimum receiving interval **730**. Terminating VTEP **212** then transmits the configured BFD data packet **302** to originating VTEP **204** via link **210**.

Upon receiving BFD data packet **302** from terminating VTEP **212**, originating VTEP **204** negotiates each timer (e.g., desired minimum transmission interval **728** and required minimum receiving interval **730**) to the respective slower value between initial NVGRE BFD data packet **300** from originating VTEP **204** and responding BFD data packet **302** from terminating VTEP **212** to establish the BFD session. For example, desired minimum transmission interval **728** is negotiated to be the slower value as received from initial NVGRE BFD data packet **300** (sent from originating VTEP **204** to terminating VTEP **212**) and responding BFD data packet **302** (sent from terminating VTEP **212** to originating VTEP **204**). In another example, required minimum receiving interval **730** is negotiated to be the slower value as received from initial NVGRE BFD data packet **300** and responding BFD data packet **302**. Originating VTEP **204** and terminating VTEP **212** also associate VSID **410** to discriminator values (e.g., my discriminator **724**, your discriminator **726**) to identify the particular NVGRE tunnel.

Once the BFD session is established, originating VTEP **204** will periodically transmit initial BFD packets and terminating VTEP **212** will respond with reply BFD packets in accordance with the timer values. The initial BFD packets and reply BFD packets are encapsulated using NVGRE and transmitted over the NVGRE tunnel. The initial BFD packets are periodically transmitted in accordance with the negotiated desired minimum transmission interval **728**. When either originating VTEP **204** or terminating VTEP **212** stop receiving the BFD packets at the agreed upon time intervals, this may be indicative of a communication failure. For example, when originating VTEP **204** does not receive a reply BFD packet from terminating VTEP **212** during an expected receiving time interval, as provided for in required minimum receiving interval **730**, this may be indicative of a communication failure. In another example, when terminating VTEP **212** does not receive an initial BFD packet from originating VTEP **204** during an expected time period, as provided for in desired minimum transmission interval **728**, this may be indicative of a communication failure.

In one embodiment, the NVGRE tunnel will be declared down after missing a particular number of (e.g., consecutive) BFD packets. The particular number of BFD packets missed may be the number of BFD packets missed at originating VTEP **204** and terminating VTEP **212**. The particular number of missed BFD packets is based on detection time multiplier **720** of BFD header **314**. Any state on originating VTEP **204** or terminating VTEP **212** that is created by virtue of the NVGRE tunnel will be removed once the NVGRE tunnel is declared down.

Advantageously, system **200** is configured to implement rapid fault detection using BFD over NVGRE tunnels. This allows system **200** to more quickly establish alterative paths.

FIG. **8** shows a flow diagram of a method **800** for detecting communication failures at an originating VTEP, in accordance with one or more embodiments. At step **802**, an

NVGRE data packet is generated in accordance with NVGRE protocols at an originating VTEP. At step **804**, a BFD data packet is encapsulated in the NVGRE data packet at the originating VTEP to generate an NVGRE BFD data packet. The BFD data packet may be generated by a source device or by an originating application, such as, e.g., a BFD task of the originating VTEP. At step **806**, the NVGRE BFD data packet is configured to indicate that the NVGRE BFD data packet includes a BFD frame. For example, the NVGRE BFD data packet may be configured to indicate a BFD frame by setting a router alert option in the outer NVGRE header of the NVGRE BFD data packet and by setting a destination MAC address in inner Ethernet header of the NVGRE BFD data packet to a well-defined, predetermined value (e.g., 00-00-5E-90-XX-XX, where X is any hexadecimal digit, e.g., a value assigned by IANA).

In one embodiment, the NVGRE BFD data packet is further configured by the originating VTEP as follows. The VSID of the outer NVGRE header of the NVGRE BFD data packet is set to the same as that of the NVGRE segment (or tunnel) that is being verified. The source MAC address in the inner Ethernet header is set to the MAC address of the originating VTEP. A source address of an inner IP header of the NVGRE BFD data packet is set to a routable address of the originating VTEP. The destination address of the inner IP header is set to a randomly chosen IPv4 address from the range 127/8 or an IPv6 address from the range 0:0:0:0:0:FFFF:127/104, and the time to live is set to **255**. A my discriminator field in an inner BFD header of the NVGRE BFD data packet is set to any valid value and a your discriminator field is set to zero. A desired minimum transmitting interval and a required minimum receiving interval are also set.

At step **808**, the NVGRE BFD data packet is transmitted from the originating VTEP to a terminating VTEP to establish a BFD session over an NVGRE tunnel. Terminating VTEP decapsulates the BFD data packet and sets the your discriminator field in the BFD header to the my discriminator value in the received NVGRE BFD data packet. Terminating VTEP also sets a desired minimum transmitting interval and a required minimum receiving interval. Terminating VTEP then sends the BFD data packet to originating VTEP. Timer values for the desired minimum transmitting interval and the required minimum receiving interval are each negotiated to a slower value between the value indicated by the originating VTEP and the value indicated by the terminating VTEP. The originating VTEP and the terminating VTEP also associate the VSID to the discriminator values to identify a particular NVGRE tunnel.

At step **810**, a communication status of the NVGRE tunnel for the BFD session is determined by the originating VTEP based on a reply BFD packet received from the terminating VTEP in accordance with the negotiated receiving time interval. In one embodiment, when originating VTEP does not receive a BFD packet within the negotiated time for a particular number of intervals (as set in detection time multiplier field in the inner BFD header), the NVGRE tunnel is declared down. For example, if, e.g., three BFD packets each are not received within their respective receiving time interval, the NVGRE tunnel is declared down. Any state on the VTEP created by virtue of the NVGRE tunnel will be removed once the tunnel is declared down.

FIG. **9** shows a flow diagram of a method **900** for detecting communication failures by a terminating VTEP, in accordance with one or more embodiments. At step **902**, an NVGRE BFD data packet is received by the terminating VTEP from an originating VTEP. The NVGRE BFD data packet comprises an NVGRE data packet generated in accordance with NVGRE protocols encapsulating a BFD data packet. The NVGRE BFD data packet may be configured as discussed above. At step **904**, the terminating VTEP identifies the NVGRE BFD data packet as including a BFD frame to establish a BFD session over an NVGRE tunnel. In one embodiment, the terminating VTEP identifies the NVGRE BFD data packet as including a BFD frame based on a router alert option set in the outer NVGRE header of the NVGRE BFD data packet and a well-defined, predetermined value of the destination MAC address in the inner Ethernet header of the NVGRE BFD data packet.

At step **906**, a communication status of the NVGRE tunnel is determined by the terminating VTEP for the BFD session based on an initial BFD data packet received from the originating VTEP in accordance with a receiving time interval. In one embodiment, when terminating VTEP does not receive a BFD packet within the negotiated time for a particular number of intervals (as set in detection time multiplier field in the inner BFD header), the NVGRE tunnel is declared down. Any state on the VTEP created by virtue of the NVGRE tunnel will be removed once the tunnel is declared down.

Systems, apparatuses, and methods described herein may be implemented using digital circuitry, or using one or more computers using well-known computer processors, memory units, storage devices, computer software, and other components. Typically, a computer includes a processor for executing instructions and one or more memories for storing instructions and data. A computer may also include, or be coupled to, one or more mass storage devices, such as one or more magnetic disks, internal hard disks and removable disks, magneto-optical disks, optical disks, etc.

Systems, apparatus, and methods described herein may be implemented using computers operating in a client-server relationship. Typically, in such a system, the client computers are located remotely from the server computer and interact via a network. The client-server relationship may be defined and controlled by computer programs running on the respective client and server computers.

Systems, apparatus, and methods described herein may be implemented within a network-based cloud computing system. In such a network-based cloud computing system, a server or another processor that is connected to a network communicates with one or more client computers via a network. A client computer may communicate with the server via a network browser application residing and operating on the client computer, for example. A client computer may store data on the server and access the data via the network. A client computer may transmit requests for data, or requests for online services, to the server via the network. The server may perform requested services and provide data to the client computer(s). The server may also transmit data adapted to cause a client computer to perform a specified function, e.g., to perform a calculation, to display specified data on a screen, etc. For example, the server may transmit a request adapted to cause a client computer to perform one or more of the method steps described herein, including one or more of the steps of FIGS. **8** and **9**. Certain steps of the methods described herein, including one or more of the steps of FIGS. **8** and **9**, may be performed by a server or by another processor in a network-based cloud-computing system. Certain steps of the methods described herein, including one or more of the steps of FIGS. **8** and **9**, may be performed by a client computer in a network-based cloud computing system. The steps of the methods described herein, including one or more of the steps of FIGS. **8** and **9**, may be performed by a server and/or by a client computer in a network-based cloud computing system, in any combination.

Systems, apparatus, and methods described herein may be implemented using a computer program product tangibly embodied in an information carrier, e.g., in a non-transitory machine-readable storage device, for execution by a programmable processor; and the method steps described herein, including one or more of the steps of FIGS. **8** and **9**, may be implemented using one or more computer programs that are executable by such a processor. A computer program is a set of computer program instructions that can be used, directly or indirectly, in a computer to perform a certain activity or bring about a certain result. A computer program can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment.

A high-level block diagram **1000** of an example computer that may be used to implement systems, apparatus, and methods described herein is depicted in FIG. **10**. Computer **1002** includes a processor **1004** operatively coupled to a data storage device **1012** and a memory **1010**. Processor **1004** controls the overall operation of computer **1002** by executing computer program instructions that define such operations. The computer program instructions may be stored in data storage device **1012**, or other computer readable medium, and loaded into memory **1010** when execution of the computer program instructions is desired. Thus, the method steps of FIGS. **8** and **9** can be defined by the computer program instructions stored in memory **1010** and/or data storage device **1012** and controlled by processor **1004** executing the computer program instructions. For example, the computer program instructions can be implemented as computer executable code programmed by one skilled in the art to perform the method steps of FIGS. **8** and **9**. Accordingly, by executing the computer program instructions, the processor **1004** executes the method steps of FIGS. **8** and **9**. Computer **1002** may also include one or more network interfaces **1006** for communicating with other devices via a network. Computer **1002** may also include one or more input/output devices **1008** that enable user interaction with computer **1002** (e.g., display, keyboard, mouse, speakers, buttons, etc.).

Processor **1004** may include both general and special purpose microprocessors, and may be the sole processor or one of multiple processors of computer **1002**. Processor **1004** may include one or more central processing units (CPUs), for example. Processor **1004**, data storage device **1012**, and/or memory **1010** may include, be supplemented by, or incorporated in, one or more application-specific integrated circuits (ASICs) and/or one or more field programmable gate arrays (FPGAs).

Data storage device **1012** and memory **1010** each include a tangible non-transitory computer readable storage medium. Data storage device **1012**, and memory **1010**, may each include high-speed random access memory, such as dynamic random access memory (DRAM), static random access memory (SRAM), double data rate synchronous dynamic random access memory (DDR RAM), or other random access solid state memory devices, and may include non-volatile memory, such as one or more magnetic disk storage devices such as internal hard disks and removable disks, magneto-optical disk storage devices, optical disk storage devices, flash memory devices, semiconductor memory devices, such as erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), compact disc read-only memory (CD-ROM), digital versatile disc read-only memory (DVD-ROM) disks, or other non-volatile solid state storage devices.

Input/output devices **1008** may include peripherals, such as a printer, scanner, display screen, etc. For example, input/output devices **1008** may include a display device such as a cathode ray tube (CRT) or liquid crystal display (LCD) monitor for displaying information to the user, a keyboard, and a pointing device such as a mouse or a trackball by which the user can provide input to computer **1002**.

Any or all of the systems and apparatus discussed herein, including elements of communications system **100** of FIG. **1** and system **200** of FIG. **2**, may be implemented using one or more computers such as computer **1002**.

One skilled in the art will recognize that an implementation of an actual computer or computer system may have other structures and may contain other components as well, and that FIG. **10** is a high level representation of some of the components of such a computer for illustrative purposes.

The foregoing Detailed Description is to be understood as being in every respect illustrative and exemplary, but not restrictive, and the scope of the invention disclosed herein is not to be determined from the Detailed Description, but rather from the claims as interpreted according to the full breadth permitted by the patent laws. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the present invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention. Those skilled in the art could implement various other feature combinations without departing from the scope and spirit of the invention.

The invention claimed is:

1. A method, comprising:

generating, at an originating virtual tunnel end point (VTEP), a network virtualization using generic routing encapsulation (NVGRE) data packet in accordance with NVGRE protocols;

encapsulating a bidirectional forwarding detection (BFD) data packet in the NVGRE data packet to generate an NVGRE BFD data packet;

transmitting the NVGRE BFD data packet to a terminating VTEP to establish a BFD session over an NVGRE tunnel;

receiving a reply BFD data packet from the terminating VTEP, the reply BFD data packet having a your discriminator field in a BFD header set to a value equal to a my discriminator field in a BFD header of the NVGRE BFD data packet;

negotiating a receiving time interval to be a slower of a value set in a required minimum receiving interval field of the NVGRE BFD data packet and a value set in a required minimum receiving interval field of the reply BFD data packet; and

determining a communication status of the NVGRE tunnel for the BFD session based on the reply BFD data packet received from the terminating VTEP in accordance with the receiving time interval.

2. The method as recited in claim **1**, further comprising:

configuring the NVGRE BFD data packet to provide an indication that the NVGRE BFD data packet includes a BFD frame.

3. The method as recited in claim 2, wherein configuring the NVGRE BFD data packet to provide the indication that the NVGRE BFD data packet includes the BFD frame further comprises:

setting a router alert option in an outer NVGRE header of the NVGRE BFD data packet; and

setting a destination media access control (MAC) address in an inner Ethernet header of the NVGRE BFD data packet to a predetermined value.

4. The method as recited in claim 1, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel based on not receiving the reply BFD data packet from the terminating VTEP within the receiving time interval.

5. The method as recited in claim 1, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel to be down when a particular number of reply BFD data packets are not received within their respective receiving time interval.

6. The method as recited in claim 1, wherein determining the communication status of the NVGRE tunnel further comprises:

sending initial BFD data packets to the terminating VTEP based on a transmission time interval.

7. A method, comprising:

receiving, at a terminating virtual tunnel end point (VTEP), a network virtualization using generic routing encapsulation (NVGRE) bidirectional forwarding detection (BFD) data packet from an originating VTEP to establish a BFD session over an NVGRE tunnel, the NVGRE BFD data packet comprising an NVGRE data packet in accordance with NVGRE protocols encapsulating a BFD data packet;

sending a reply BFD data packet to the originating VTEP, the reply BFD data packet having a your discriminator field in a BFD header set to a value equal to a my discriminator field in a BFD header of the NVGRE BFD data packet;

negotiating a receiving time interval to be a slower of a value set in a required minimum receiving interval field of the NVGRE BFD data packet and a value set in a required minimum receiving interval field of the reply BFD data packet; and

determining a communication status of the NVGRE tunnel for the BFD session based on an initial BFD data packet received from the originating VTEP in accordance with the receiving time interval.

8. The method as recited in claim 7, wherein receiving, at the terminating VTEP, the NVGRE BFD data packet from the originating VTEP to establish the BFD session over the NVGRE tunnel further comprises:

identifying the NVGRE BFD data packet as including a BFD frame.

9. The method as recited in claim 8, wherein identifying the NVGRE BFD data packet as including the BFD frame is based on a router alert option set in an outer NVGRE header of the NVGRE BFD data packet and a predetermined value set in a destination media access control (MAC) address in an inner Ethernet header of the NVGRE BFD data packet.

10. The method as recited in claim 7, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel based on not receiving the initial BFD data packet from the originating VTEP within the receiving time interval.

11. The method as recited in claim 7, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel to be down when a particular number of initial BFD data packets are not received within their respective receiving time interval.

12. The method as recited in claim 7, wherein determining the communication status of the NVGRE tunnel further comprises:

sending reply BFD data packets to the origination VTEP based on a transmission time interval.

13. A non-transitory computer readable medium storing computer program instructions which, when executed on a processor, cause the processor to perform operations comprising:

generating, at an originating virtual tunnel end point (VTEP), a network virtualization using generic routing encapsulation (NVGRE) data packet in accordance with NVGRE protocols;

encapsulating a Bidirectional Forwarding Detection (BFD) data packet in the NVGRE data packet to generate an NVGRE BFD data packet;

transmitting the NVGRE BFD data packet to a terminating VTEP to establish a BFD session over an NVGRE tunnel;

receiving a reply BFD data packet from the terminating VTEP, the reply BFD data packet having a your discriminator field in a BFD header set to a value equal to a my discriminator field in a BFD header of the NVGRE BFD data packet;

negotiating a receiving time interval to be a slower of a value set in a required minimum receiving interval field of the NVGRE BFD data packet and a value set in a required minimum receiving interval field of the reply BFD data packet; and

determining a communication status of the NVGRE tunnel for the BFD session based on the reply BFD data packet received from the terminating VTEP in accordance with the receiving time interval.

14. The computer readable medium as recited in claim 13, the operations further comprising:

configuring the NVGRE BFD data packet to provide an indication that the NVGRE BFD data packet includes a BFD frame by setting a router alert option in an outer NVGRE header of the NVGRE BFD data packet and setting a destination media access control (MAC) address in an inner Ethernet header of the NVGRE BFD data packet to a predetermined value.

15. The computer readable medium as recited in claim 13, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel based on not receiving the reply BFD data packet from the terminating VTEP within the receiving time interval.

16. The computer readable medium as recited in claim 13, wherein determining the communication status of the NVGRE tunnel further comprises:

determining the communication status of the NVGRE tunnel to be down when a particular number of reply BFD data packets are not received within their respective receiving time interval.

17. The computer readable medium as recited in claim **13**, wherein determining the communication status of the NVGRE tunnel further comprises:

sending initial BFD data packets to the terminating VTEP based on a transmission time interval.

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